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Post-Mining Groundwater Supply Potential At The Highvale Site: Plains Hydrology and Reclamation Project

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

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Report
#RRTAC 86-7

POST-MINING GROUNDWATER SUPPLY POTENTIAL
AT THE HIGHVALE SITE:
PLAINS HYDROLOGY & RECLAMATION PROJECT

by

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for

Reclamation Research
Technical Advisory Committee
of the
Alberta Land Conservation
and
Reclamation Council

1986

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide Government and Industry staff with up to date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a chairman from the Department of the Environment and two deputy chairman from the Department of Forestry, Lands & Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the research program the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC). The Committee first met in March, 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands & Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

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PREFACE

This is one of a series of reports that presents the findings of the Plains Hydrology and Reclamation Project (PHRP), an interdisciplinary study that focuses primarily on hydrologic aspects of reclamation of surface coal mines in the Plains of Alberta. This research has been conducted by the Alberta Research Council, as part of the Alberta Government's Reclamation Research Program. The program is managed by the Land Conservation and Reclamation Council and is supported by the Heritage Trust Fund.

The focus of the PHRP is to develop a predictive framework that will permit projection of success for reclamation and impact of mining on water resources on a long-term basis. The predictive framework is based on an understanding of processes acting within the landscape so that in the future, mine sites that are not totally analogous to those that have been studied can be evaluated as well.

The project involves a holistic approach to reclamation by integration of studies of geology, hydrogeology, and soils, not only in the proposed mining area, but also in the adjoining unmined areas. This approach permits the assessment of impacts and of long-term performance, not only in reclaimed areas, but also in the surrounding area.

The research of the PHRP has been directed toward the following two major objectives and eight subobjectives.

Objective A

To evaluate the potential for reclamation of lands to be surface mined. The focus is on features of the landscape that make it productive in a broad sense not restricted to revegetation. This objective was organized into five subobjectives:

1. To assess and evaluate the potential for long-term degradation of reclaimed soils through salt buildup.
2. To assess and evaluate the effectiveness of topographic modification and selective placement of materials to

mitigate deleterious impacts on chemical quality of groundwater.

3. To assess the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations.
4. To evaluate the productivity potential (capability) of post-mining landscapes and the significance of changes in capability as a result of mining.
5. To assess and evaluate limitations to post-mining land use posed by physical instability of cast overburden.

Objective B

To evaluate the long-term impact of mining and reclamation on water quantity and quality. This objective was organized into three subobjectives:

1. To assess and evaluate the long-term alteration of quality of groundwater in cast overburden and surface water fed from mine spoil as a result of the generation of weathering products.
2. To assess and evaluate infiltration, groundwater recharge, and groundwater-surface water interactions within cast overburden.
3. To characterize the groundwater chemistry generated within cast overburden.

Studies directed at these objectives began in 1979 at the Battle River site in east-central Alberta. Work began in 1982 at a second study area at Highvale Mine south of Lake Wabamun. Significant progress had been made on all project objectives by the end of the first phase of study in March 1984. This present series of reports summarizes the state of our knowledge at the end of this first phase of study. Work is now continuing on the Phase II objectives to gain an even greater understanding of the complex physical and chemical processes in reclaimed landscapes.

This report deals with studies directed at Subobjective A-3: To assess the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The focus of study, implicit in the above subobjective statement, is post-mining groundwater availability, as opposed to surface water supply.

This report is an assessment of post-mining groundwater potential of the Highvale Mine Site, and is to a large degree an analysis of existing data compiled by Monenco Consultants for TransAlta Utilities Ltd. Geologic and hydrogeologic data produced by the PHRP is also incorporated into this study, but comprised a relatively small data base compared to the Monenco data. This report is intended to provide a characterization of both existing and potential post-mining groundwater supplies, and to draw conclusions regarding the suitability of potential post-mining aquifers to meet the requirements of domestic water supplies.

ABSTRACT

Domestic water supply requirements in the Highvale Study Area are currently met by production from aquifers in or above the Ardley Coal Zone. These aquifers will be disrupted by mining, and the resulting groundwater within spoil is generally unsatisfactory for exploitation primarily because of poor water quality, but also because of variable transmissivity. The best potential post-minin groundwater source in the Highvale Study Area is from sandstone bodies that form an aquifer within the Upper Horseshoe Canyon Formation, situated stratigraphically below the Ardley Coal Zone. These sandstone bodies are laterally very discontinuous, and where present, generally of inadequate transmissivity to meet domestic water supply needs. On the basis of 14 test sites, this aquifer produced enough water to meet minimum standards only in the area Sec 21, Tp 52, R 5, W 5 Mer. Over the rest of the site it is not likely that significant zones of adequate transmissivity will be found, although small, local sandstone bodies might be identified by additional test drilling. In this event, however, such sandstone bodies may not prove to be good long-term replacement water supplies because of their limited lateral extent and limited recharge potential, which in many cases is likely inadequate to sustain withdrawal.

Overall then, it is highly unlikely that there exists a viable long-term replacement groundwater supply over much of the Highvale Study Area. Therefore, an alternative to groundwater as it is presently used will probably have to be considered to support post-mining land use that includes a residential component.

ACKNOWLEDGEMENTS

This work was funded by the Alberta Heritage Trust Fund and administered by the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council. TransAlta Utilities Ltd. was particularly helpful in making available reports and data collected by Monenco Ltd.

1. INTRODUCTION

The objective of this study is to assess the availability of groundwater supply in or beneath the cast overburden to support post-mining land use, including both quantity and quality considerations, in the Highvale Study Area (Figure 1). The following report provides a characterization of the existing groundwater supply in the Highvale Study Area based primarily on domestic wells and an evaluation of the post-mining groundwater supply potential of aquifers located stratigraphically below the zone of disturbance.

The premining water-supply requirements for rural residences in the Highvale Study Area are, in almost all cases, satisfied by groundwater from single wells, without water-storage systems at surface. The intent of this report is to examine the potential for post-mining groundwater supply to provide a comparable capability. To examine alternatives to the single-well groundwater supply system is beyond the scope of this report, although a number of alternatives do exist. Similarly, this study is based on an evaluation of water quality as available in post-mining aquifers, without considering extraordinary water treatment measures (such as reverse-osmosis systems) for modifying water quality.

The present permit area of the Highvale Mine is made up of approximately 118 km^2 of mixed agricultural land and wildland. The surface mining of coal in the Highvale Study Area will disrupt a major sandstone aquifer in the bedrock overburden (Paskapoo Formation) as well as the coal zone itself, which is a minor aquifer. Given that approximately 12 000 ha of land within the present TransAlta Utilities Ltd. Mine permit boundary will be ultimately disturbed by surfacing mining, it is necessary to evaluate the water supply potential of the post-mining landscape in order to determine the long-term suitability of the reclaimed site to support the present type and extent of human activity (primarily rural agricultural residences).

Previous studies of groundwater conditions and water supply have been done by Montreal Engineering Company Ltd. (Monenco Ltd.)

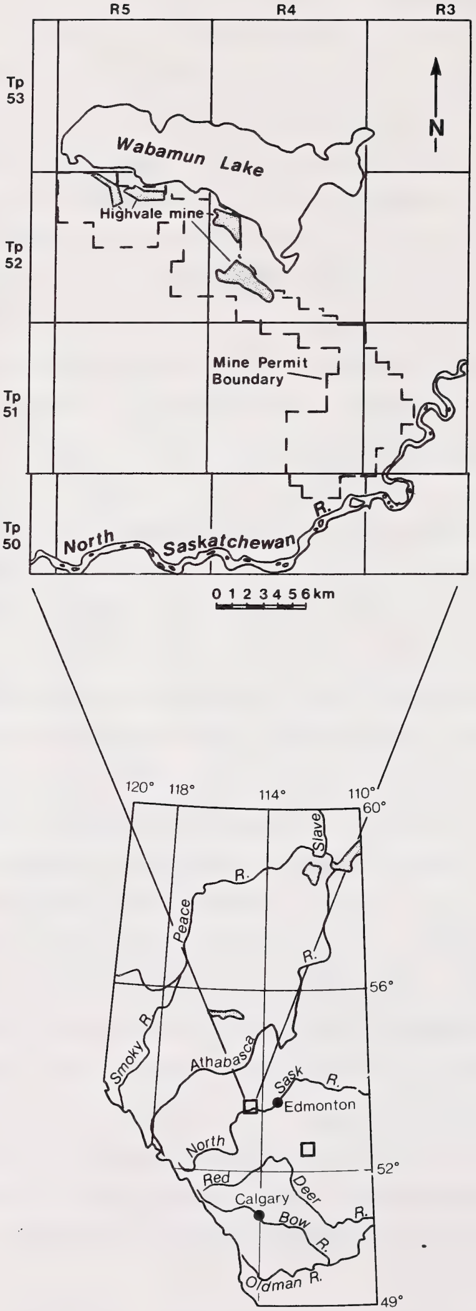

Figure 1. Location of the Highvale Study Area.

for TransAlta Utilities Ltd. (Montreal Engineering Ltd. 1978, 1979; Monenco Ltd. 1981a, 1981b, 1982). The data base established by these studies has been utilized extensively in this report, particularly in terms of domestic well characterization. Data collected by Research Council that formed part of the basis for conclusions in this report is presented by Trudell et al. 1985.

This study of the post-mining water supply potential of the Highvale Study Area was initiated in mid-1982 as part of the PHRP within the Research Council.

2. GENERAL GEOLOGY AND HYDROGEOLOGY

The Paskapoo Formation is the youngest of three formations that comprise the shallow bedrock in the Highvale Study Area (Figure 2). It consists of the basal Scollard Member, which includes the Ardley Coal Zone, and an overlying sequence of sandstone, siltstone, and shale that makes up the bedrock overburden. This bedrock overburden generally includes a massive sandstone unit, which is an important aquifer (Figure 2). The Ardley Coal Zone, in the upper part of the Scollard Member, is approximately 15 m thick and generally consists of six laterally continuous seams. The Ardley Coal Zone is utilized as a source of groundwater primarily along the subcrop, south of Lake Wabamun, where it is highly fractured. It is underlain by a sequence of sandstone and siltstone which makes up the lower part of the Scollard Member.

The Paskapoo Formation is underlain by the Battle Formation, a laterally continuous shale unit that is a regional aquitard. The Upper Horseshoe Canyon Formation, which consists of laterally discontinuous fluvial sediment, primarily siltstone and shale, with channel sandstone bodies, lies beneath the Battle Formation. The Upper Horseshoe Canyon Formation is an important aquifer only in the eastern part of the Highvale area, updip from the coal subcrop, where the rocks occur at shallow depths and are probably fractured.

The drift in the Highvale Study Area is mainly till, which is generally less than 6 m thick and in places is capped by a thin veneer of lacustrine sediment. Locally, sand lenses of limited lateral extent may be utilized as a source of groundwater, particularly in the southeast part of the study area.

The groundwater-flow patterns in the Highvale Study Area are controlled by topography and the outcrop/subcrop pattern of shallow hydrostratigraphic units. In the portion of the groundwater-flow system in or above the Ardley Coal Zone, flow is occurring from the uplands south of Lake Wabamun, in a north or northeasterly direction, toward the lake. The hydraulic head in the

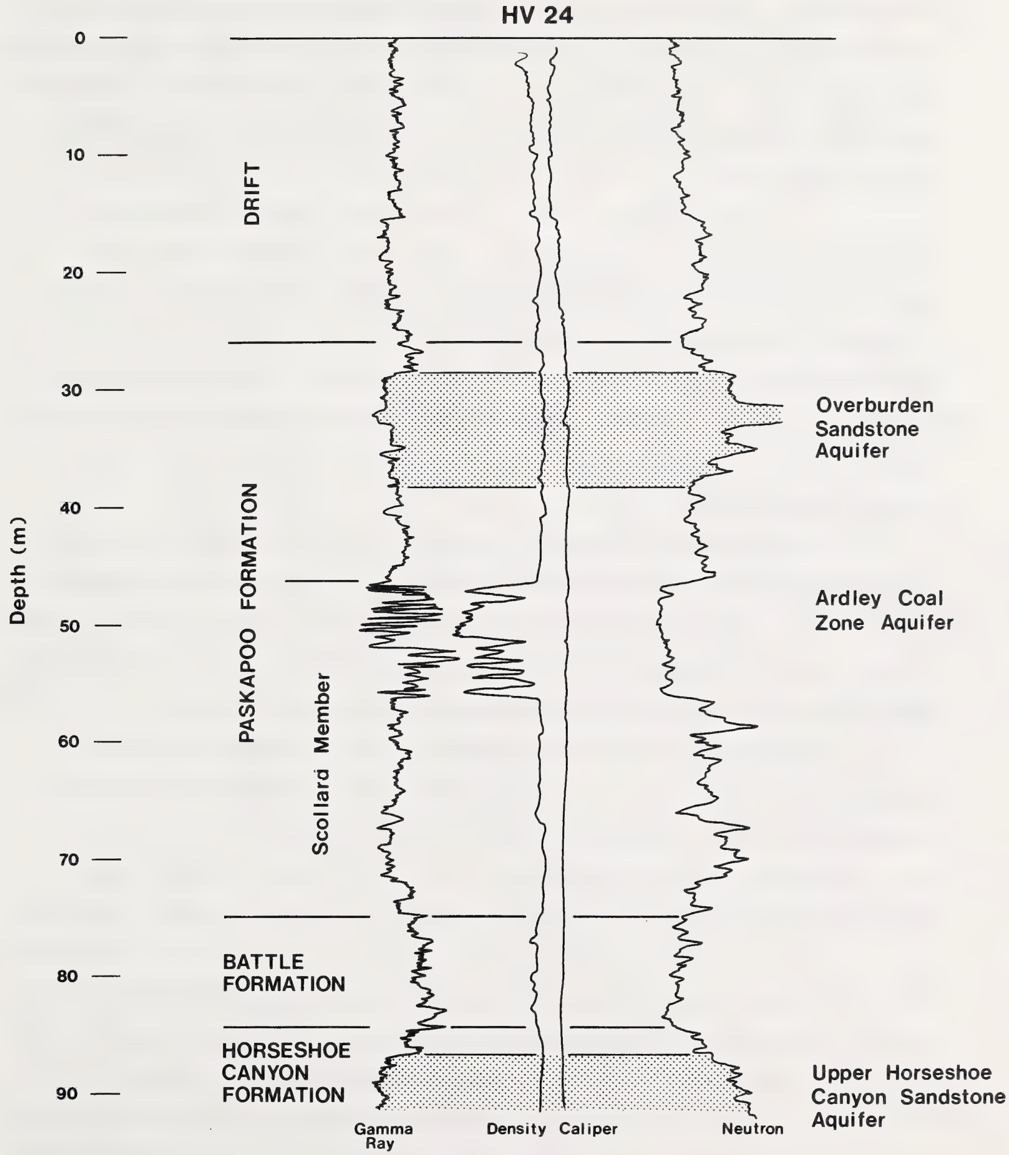

Figure 2. Generalized stratigraphic column showing principal aquifers, Highvale Project Area.

coal and overburden aquifers is in almost all cases above the level of Lake Wabamun. The coal zone and overburden aquifers generally subcrop south of the lake, therefore although flow is directed toward Lake Wabamun, discharge to the lake directly from these aquifers is probably not occurring, except in places where the coal zone subcrops below the lake. However, it is likely that Lake Wabamun is directly receiving some groundwater discharge from shallow surficial or bedrock aquifers.

In the southeast part of the study area, groundwater flow in the coal zone and overburden is from the uplands toward the subcrop, resulting in flow directions ranging from southward to eastward. The North Saskatchewan River is the regional groundwater drain for the southern part of the study area. A local groundwater divide runs east-west and separates groundwater flow directed north toward Lake Wabamun and that directed south toward the North Saskatchewan River.

The vertical hydraulic gradients at the Highvale Site indicate that the site is predominantly a recharge area. Downward vertical gradients are present in nearly all settings, except perhaps in very local settings, where flow systems are shallow. In the area where the coal and overburden sandstone subcrop along the south shore of Lake Wabamun, below an escarpment approximately 70 m in height, groundwater discharge conditions are present. Vertical hydraulic gradients in this setting are generally low (less than 0.2) and in some cases are upward-directed. It is likely that, under these conditions, groundwater-flow directions are lateral, with discharge occurring along the subcrop face.

The chemical makeup of groundwater in the Highvale Study Area is, in general, dominated by sodium and bicarbonate, with Total Dissolved Solids (TDS) in the range from 1000 to 2000 mg/L.

In the drift, the groundwater composition is more variable than in the bedrock, with the highest levels of calcium and sulfate found in this stratigraphic unit. There is a tendency for the concentration of both calcium and sulfate to decrease with depth whereas concentrations of sodium and bicarbonate tend to increase with depth. This trend is common in shallow groundwater systems in the Plains, and is probably related to a loss of calcium and increase in sodium by ion exchange within the bedrock together with sulfate reduction, which produces bicarbonate. In addition, the removal of calcium from the aqueous phase by ion exchange may disrupt the equilibrium of the groundwater with respect to calcite, causing calcite dissolution and corresponding increase in dissolved bicarbonate.

2.1 GENERALIZED DOMESTIC WATER SUPPLY REQUIREMENTS

The amount of water required to adequately supply the domestic needs of a residence in a rural setting is to some degree arbitrary, but certain findings have been reported based on water-use records.

In a report titled "Soil Testing and Groundwater Supply Evaluation Guidelines for Residential Subdivisions" (Soils Branch, Earth Sciences Division, Environmental Protection Services, Alberta Environment February 1983), the following statement is made regarding the water supply requirements for a single household:

> The requirements are currently calculated, assuming water consumption is an average of 1 091 litres/day/lot (240 Imperial gallons/day/lot). These requirements include an amount necessary for human consumption and sanitary purposes, but does not provide for fire protection, irrigation, livestock, or any other outdoor requirements.

Because of the restriction on nonhuman uses, this figure is considered to represent a minimum value. According to Hammer (1977) the average daily water use in the western United States is 1 700 L/d per residence. Both of these figures are daily averages. In calculating water supply requirements (without storage), it is common engineering practice to use the maximum hourly demand as the design criterion; a mean maximum hourly rate is typically 3.6 times the daily average (Hammer 1977). Consequently, the maximum hourly rate for the design of a water supply would range from 164 L/h (Alberta) to 255 L/h (western United States). These rates correspond 0.05 to 0.07 L/s.

The well yield values determined from short-term pumping tests or single-well response tests are based on a number of assumptions and simplifications, and also represent the testing of a relatively small volume of aquifer material. To accommodate these effects a factor of safety of at least 50 percent, is commonly included in the calculation of well yields. In recognition of this, the required well yield (determined from short-term tests) to adequately supply the domestic requirements specified above (0.05 to 0.07 L/s) should be at least 0.08 to 0.10 L/s.

3. EXISTING WATER SUPPLY

Practically all of the domestic water wells within the limits of mining in the Highvale Study Area are completed in or above the Ardley Coal Zone (Montreal Engineering 1978, 1979). Only in the area updip from the coal subcrop, beyond the limit of mining, are aquifers stratigraphically below the coal zone utilized to a significant degree. In this area these aquifers are very shallow and are overlain by only a thin veneer of drift.

Montreal Engineering (1978, 1979) identified 304 domestic wells in the Highvale Study Area. Of these, 59 wells were completed in bedrock stratigraphically updip from the coal and, therefore, beyond the limit of potential mining. The stratigraphic unit of the completion could not be identified for 49 wells. Ninety-seven percent of the remaining 196 wells were completed in or above the Ardley Coal Zone, with 62 percent in bedrock overburden, 18 percent in the coal zone, and 17 percent in the drift. Only 3 percent (6 wells) were completed in aquifers below the coal zone, and it is possible that the open interval for some of these wells extended into or above the coal zone.

Of 134 domestic water wells in the Highvale area for which a pumping rate was recorded by Monenco (1981b), 92 percent were producing water at a rate greater than 0.07 L/s and 96 percent were pumping at a rate above 0.05 L/s. Only 11 of the 134 wells were pumping at a rate below 0.07 L/s and 5 wells were pumping at less than 0.05 L/s. The pumping rate reported by Monenco Ltd. represents the setting of the well production equipment (pump, control orifice, etc.) and is not a time measure of aquifer characteristics. Consequently, these pumping rates are not directly comparable to well-yield values calculated from pumping tests (such as the 20-year safe yield, Q_{20}), however they do provide some indication of the long term yield characteristics of the premining aquifers. The lowest reported yield was 0.04 L/s, however, in the above report no reference was made as to whether or not a water storage system was being used. Considering that the mean pumping rate for these 134 domestic wells is 0.45 L/s (SD = 0.53), it is reasonable to define an 'adequate' supply as 0.05 to 0.07 L/s. This is not to say that a residence could not get by on less; however, such low yields would be so far below the average as to be considered unreasonable and unacceptable.

The quality of water from domestic wells in the Highvale Study Area has been characterized on the basis of 162 samples collected by Montreal Engineering (1978, 1979). The distribution of TDS and sulfate concentrations from domestic wells is illustrated in Figures 3 and 4. Water from domestic wells in the Highvale area is of relatively low salinity, with 90 percent of the wells producing water with less than 1500 mg/L TDS. Thirty-six percent of the domestic well samples met the recommended maximum TDS concentration of 500 mg/L TDS (Department of National Health and Welfare 1978), and 72 percent are below the 1000 mg/L TDS limit recommended by Alberta Environment. Ninety-seven percent of the domestic-well samples were less than the 2000 mg/L maximum TDS standard based on the onset of laxative effects on humans (McNeely et al. 1979), and 99 percent of the wells produced water with less than 3000 mg/L TDS, the standard considered to be maximum for consumption by livestock (McNeely et al. 1979).

The water quality with respect to sulfate of domestic wells in the study area is good. Ninety-seven percent of the domestic well samples have sulfate concentrations below the recommended maximum of 500 mg/L (McNeely et al. 1979), and 83 percent have concentrations of sulfate below the objective level of 150 mg/L (Department of National Health and Welfare 1979).

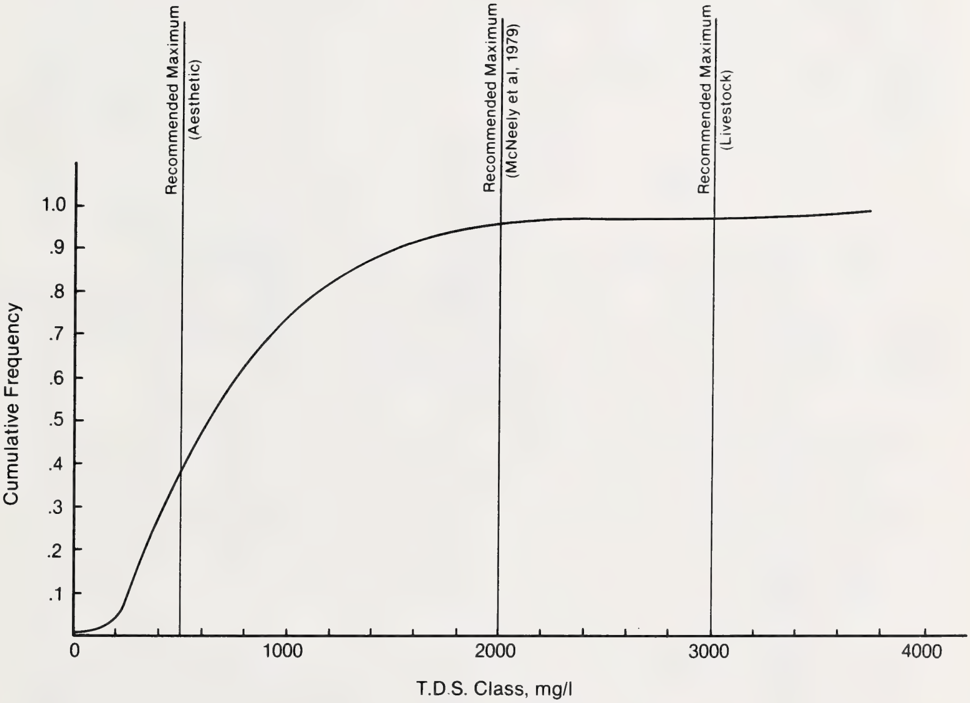

Figure 3. Distribution of Total Dissolved Solids concentrations in domestic water wells, Highvale Project Area.

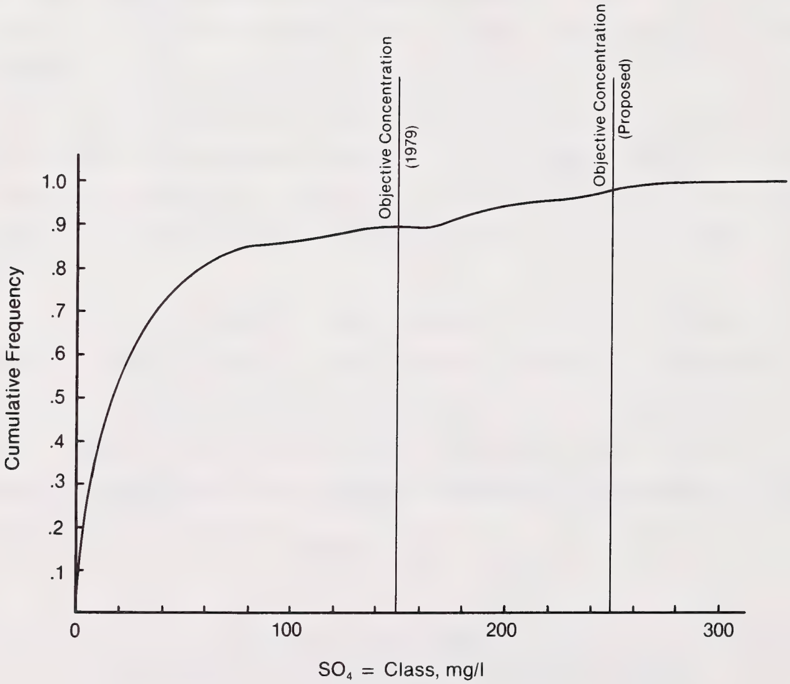

Figure 4. Distribution of sulfate concentrations in domestic water wells, Highvale Project Area.

4. POST-MINING WATER SUPPLY

The reclaimed spoil of Pit 01 at the Highvale Mine was examined to determine if the cast overburden might form a suitable post-mining aquifer. Twenty-seven piezometers in the resaturated spoil were sampled for chemical analysis (Appendix 7.1) and revealed that in almost all cases the quality of water from the spoil is too poor for water supply purposes. The mean TDS concentration of the spoil groundwater is 3 513 mg/L, with 85 percent of the samples having in excess of 2000 mg/L. The 15 percent of the samples with less than 2000 mg/L TDS occur in isolated lenses within the spoil mass and in no way represent a secure water supply. In addition to the relatively high TDS concentrations, the spoil groundwater has much higher concentrations of sulfate than the existing water supply. Sixty-nine percent of the spoil groundwater samples exceeded the objective sulfate concentration of 150 mg/L, compared to only 17 percent of the domestic well samples.

The transmissivity of the spoil, based on single-well response tests in Pit 01, is highly variable. On the basis of measurements from 15 piezometers at 10 sites in the reclaimed part of Pit 01, the transmissivity of the spoil ranges from 2.6×10^{-9} m^2/s to 6.6×10^{-4} m^2/s (Appendix 7.2). Such wide variations occur over distances of 200 to 300 m, and it is not clear if the zones of high transmissivity are hydraulically connected to or isolated from each other by zones of low-permeability material. The log-mean transmissivity of 1.7×10^{-5} m^2/s, although relatively high, must be considered carefully in view of the very large standard deviation (log SD = 1.48, n = 15). Potential long-term well yields from the spoil at Pit 01 have been calculated based on the assumption that the spoil behaves as an unconfined aquifer of infinite areal extent, and that 80 percent of the saturated thickness is available for drawdown. Considering these assumptions, the mean long-term well yield from the spoil is 0.45 L/s (log SD = 0.84, n = 15), with individual values ranging from 1.3×10^{-5} L/s to 2.92 L/s (Appendix 7.2). Of the ten sites tested in Pit 01, six are capable of well yields above 0.1 L/s, although these sites are interspersed with the 4 sites providing inadequate yields. Overall, the spoil at Pit 01 appears to be capable of providing useable quantities of groundwater, although the long-term reliability of this source is not known, particularly because of the presence of low-permeability zones that may act as barriers to lateral groundwater flow in the spoil aquifer.

Sandstone horizons within the Upper Horseshoe Canyon Formation, stratigraphically below the Ardley Coal Zone, form the best potential post-mining aquifer in the Highvale area. Twenty-four percent of the existing domestic wells are completed within this aquifer. Only 2 percent of the existing domestic wells, however, are completed in sandstone beds in the Upper Horseshoe Canyon Formation underlying the coal. The remainder are located to the north and east of the coal subcrop, in an area where sandstone of the Upper Horseshoe Canyon Formation either subcrops or lies under shallow cover. The relatively high transmissivity of this aquifer in the area north and east of the coal subcrop probably results from increased fracturing of the aquifer material, as opposed to a change in aquifer lithology (Montreal Engineering 1978, 1979).

The sandstone horizons that form the aquifer within the Upper Horseshoe Canyon Formation are of highly variable thickness and of limited lateral extent. These characteristics are a reflection of the low-energy, meandering-river type of environment in which the sand beds were deposited in river channels (Nurkowski and Rahmani 1984). In addition, the sand beds are generally very fine-grained, with considerable clay-sized matrix material filling the pore spaces. Even in locations where relatively thick, nonclayey sandstone bodies occur, they are generally well-cemented, and therefore of low transmissivity. As a result of the combination of these characteristics, the sandstone beds of the Upper Horseshoe Canyon Formation form a very poor aquifer.

In the portion of the study area where the upper Horseshoe Canyon sandstone aquifer underlies the coal zone, available information indicates that zones capable of yielding exploitable quantities of water occur as isolated lenses. Of 13 test sites (Appendix 7.3), yields above 0.1 L/s were found at only 1 site, located in NE, Sec 20, Tp 52, R 5, W 5 Mer (HE77-5, 0.27 L/s, Figure 5). In addition, three domestic water wells completed in the upper Horseshoe Canyon sandstone aquifer are considered to be providing adequate yields (for example, well 68A in NE, Sec 21, Tp 52, R 5, W 5 Mer recorded a yield of 0.15 L/s, Figure 5). However, because of very long screened intervals and uncertainty in locations of screened intervals and installation practice in many wells, it is difficult to state conclusively that the observed yield in domestic wells is derived from only the deep sandstone horizon, with no contribution from shallower aquifers. For example, domestic well 68A in the Highvale area is screened over 42 m and probably is drawing water from sandstone beds in the Paskapoo Formation immediately underlying the coal zone, if not from the coal zone itself. Consequently, domestic wells in general are not considered a reliable basis for evaluating the post-mining water supply potential of the Highvale site.

Additional stratigraphic information from testhole Research Council 75-74, located in NW, Sec 21, Tp 52, R 5, W 5 Mer approximately 1 km east of site HE 77-5 (Figure 5), suggests that the producing sandstone horizon encountered at HE 77-5 extends at least that far to the east. Site HE 77-4, located in NW, Sec 27, Tp 52, R 5, W 5 Mer approximately 3 km to the northeast (Figure 5), however, did not intersect any significant producing zones. Paleodrainage directions for the Upper Horseshoe Canyon Formation suggest that the sand bodies within this formation are elongated in a northwest-southeast direction (Nurkowski and Rahmani 1984). At the present spacing of testholes, which ranges from approximately 0.8 to 5 km and averages about 3 km, it is not possible to delineate the lateral extent of the sand bodies. From the available data, however, it would appear that they are on the order of 0.5 to 2 km wide and perhaps 2 to 4 km long. The number of these sandstone lenses with the combination of properties resulting in transmissivity adequate to yield useable quantities of water, however, appears to be small.

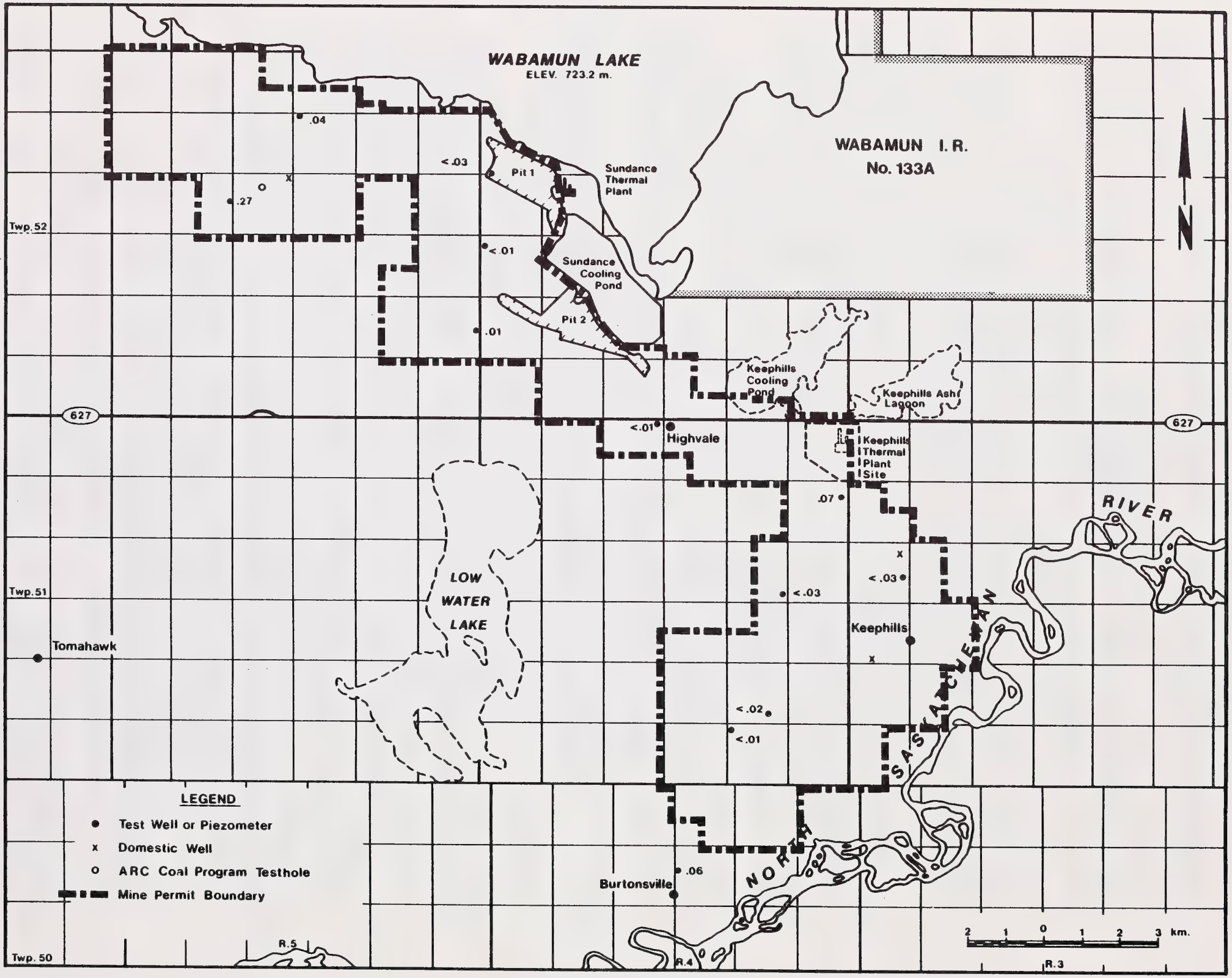

Figure 5. Yields from the upper Horseshoe Canyon sandstone aquifer.

Where adequate yields from the upper Horseshoe Canyon sandstone aquifer can be obtained, indications are that the water quality will be suitable for replacement of the premining source. On the basis of 13 samples from this aquifer (Appendix 7.4), the TDS and sulfate concentrations are comparable to those in existing domestic wells (Figures 6, 7). Ninety-seven percent of domestic wells have TDS concentrations less than the 2000 mg/L standard, compared with 92 percent (12 of 13 samples) of the samples from the upper Horseshoe Canyon sandstone aquifer (Figure 6). Similarly, 100 percent of the samples from the sandstone aquifer samples had concentrations less than the 250 mg/L sulfate standard, versus 98 percent of the domestic well samples (Figure 7).

A number of the samples from the upper Horseshoe Canyon sandstone aquifer are from wells located stratigraphically updip from the Ardley Coal Zone subcrop. For the purposes of evaluating post-mining water supply, only those wells located where the sandstone underlies the coal zone should be considered.

Six of the 13 samples from the upper Horseshoe Canyon sandstone aquifer are from areas overlain by coal and are, therefore, within the area of potential mining. The water quality of this subgroup of samples is essentially the same as for those samples from beyond the coal subcrop, although maximum TDS and sulfate concentrations are lower below the coal zone than beyond the subcrop. All of the samples from this subgroup have less than 2000 mg/L TDS and 150 mg/L sulfate. In fact, the maximum sulfate concentration within this subgroup is less than 60 mg/L. Consequently, within the proposed limit of mining the water quality in the upper Horseshoe Canyon sandstone aquifer is considered to be acceptable. The principal limitation of this aquifer, therefore, in terms of post-mining groundwater supply potential, is the erratic occurrence of zones with adequate transmissivity to meet domestic water supply requirements.

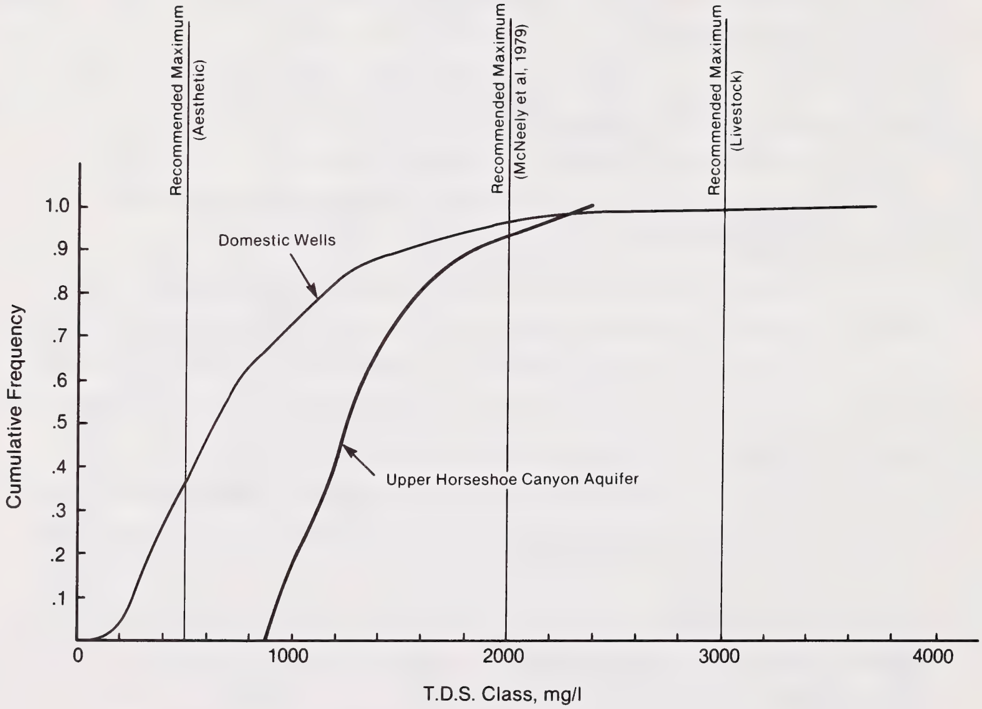

Figure 6. Distribution of Total Dissolved Solids in the upper Horseshoe Canyon sandstone aquifer, compared to domestic water wells.

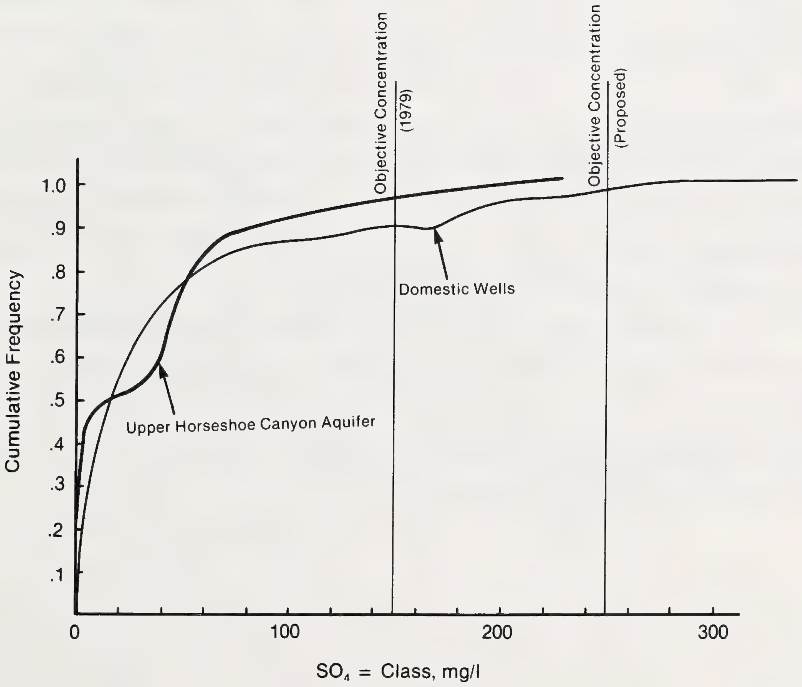

Figure 7. Distribution of sulfate concentrations in the upper Horseshoe Canyon sandstone aquifer, compared to domestic water wells.

5. CONCLUSIONS

Domestic water supply requirements in the Highvale Project Area are currently met by production from aquifers in or above the Ardley Coal Zone. These aquifers will be disrupted by mining, and the resulting groundwater in the spoil is not suitable for exploitation primarily because of poor water quality, but also because of highly variable transmissivity.

The most probable potential post-mining groundwater source in the Highvale area is from sandstone bodies that form an aquifer within the Upper Horseshoe Canyon Formation, situated stratigraphically below the Ardley Coal Zone. These sandstone bodies are laterally discontinuous and, where present, generally of inadequate transmissivity to meet domestic water supply needs. On the basis of 13 test sites, this aquifer is suitable for exploitation only in the area of Sec 21, Tp 52, R 5, W 5 Mer. Over the rest of the site, it is not likely that significant zones of adequate transmissivity will be found, although small, local sandstone bodies might be identified by additional test drilling. In this event, however, such sandstone bodies may not prove to be good long-term replacement water supplies because of their limited lateral extent and susceptibility to groundwater 'mining'.

Overall then, it is highly unlikely that there exists a viable long-term replacement groundwater supply over much of the Highvale area. Therefore, an alternative to groundwater will probably have to be considered to support a post-mining land use that includes a residential component.

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7. APPENDIX

7.1 HIGHVALE MINE SPOIL, PIT 01, MAJOR ION CHEMISTRY

All values in mg/L

Well ID	Ca^{2+}	Mg^{2+}	Na^+	K^+	$SO_4^=$	Cl^-	HCO_3^-	NO_3^-	TDS
HV2-1	28.4	4.0	919	3.3	775	3.0	1476	2.8	3232
HV2-2	6.9	3.0	1100	2.1	62	38.0	2754	52.0	4044
HV3-1	11.7	3.0	1100	2.1	117	14.0	1553	1.0	2422
HV3-2	71.0	61.0	1040	8.9	522	36.0	2613	2.0	4388
HV3-3	284.0	101.0	1370	13.0	2625	14.0	1409	4.5	5904
HV6-1	207.0	29.8	1719	15.8	3143	14.0	1689	15.6	6855
HV6-2	40.3	11.9	1529	7.7	1926	4.0	1513	13.3	5058
HV6-3	134.0	20.0	1390	12.0	2164	3.7	1372	6.9	5073
HV7-1	36.3	5.8	715	3.4	107	33.0	1478	53.1	2642
HV7-2	124.0	17.2	1044	9.7	1415	5.0	1537	4.3	4170
HV7-3	205.0	28.0	760	19.0	1335	4.0	775	1.2	3143
HV8-2	20.6	2.6	775	2.6	639	12.0	1321	1.3	2818
HV8-3	101.0	22.8	34	1.3	15	2.0	1693	12.5	1881
HV8-4	156.0	38.0	129	4.5	75	10.2	686	6.6	1273
HV9-1	12.7	0.0	1388	5.2	1840	41.0	-	3.5	4120
HV9-2	69.0	19.0	866	6.8	1026	6.3	1329	11.0	3303
HV10-1	37.6	7.8	1100	5.8	1109	10.0	1693	3.8	3981
HV10-2	73.0	14.0	1202	5.8	1346	7.1	1722	2.3	4382
HV10-3	315.0	47.6	881	11.3	1676	5.0	1369	7.2	4336
HV11-1	34.0	9.5	838	2.9	417	8.0	1761	7.8	3098
HV11-2	200.0	63.0	95	0.6	29	7.0	1025	10.3	1457
HV11-3	112.0	49.0	361	4.2	117	3.0	1289	10.8	1970
HV12-1	22.0	3.7	812	3.2	215	5.2	1839	11.0	2911
HV12-4	163.0	15.0	1875	12.0	3120	4.0	1486	0.9	6684
HV14-1	10.2	1.0	685	2.9	124	0.0	1473	0.9	2315
HV14-2	371.0	114.0	600	10.5	1969	12.0	880	19.4	3997

7.2 TRANSMISSIVITY AND YIELDS FROM RECLAIMED SPOIL, HIGHVALE MINE PIT 01

Well ID	Open Interval (m)	T (m^2/s)	Q_{20} (L/s)
HV2-1	13.4 - 14.0	3.93×10^{-4}	0.14
HV2-2	10.4 - 11.0	7.11×10^{-5}	0.06
HV3-1	13.4 - 14.0	4.00×10^{-6}	0.02
HV3-3	7.4 - 8.0	2.01×10^{-9}	<0.01
HV6-1	13.1 - 13.7	1.17×10^{-4}	0.43
HV7-1	15.7 - 16.3	2.00×10^{-5}	0.09
HV7-2	12.4 - 13.0	4.17×10^{-5}	0.19
HV8-2	15.6 - 16.2	6.58×10^{-4}	2.92
HV9-1	15.1 - 15.6	4.28×10^{-5}	0.09
HV10-1	12.2 - 12.8	3.22×10^{-5}	1.21
HV10-2	10.0 - 10.6	3.68×10^{-4}	0.10
HV11-1	13.4 - 14.0	8.94×10^{-6}	0.05
HV11-3	9.1 - 9.7	1.88×10^{-8}	<0.01
HV12-1	17.4 - 18.0	2.53×10^{-4}	0.72
HV14-1	13.7 - 14.3	6.58×10^{-6}	0.03
Mean		1.69×10^{-5}(1)	0.40(2)
Standard Deviation		1.482(1)	0.745(2)

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(1) log mean, and log Standard Deviation

(2) arithmetic mean and arithmetic Standard Deviation

7.3 YIELDS FROM THE UPPER HORSESHOE CANYON SANDSTONE AQUIFER

Site	Location Lsd,	Sec,	Tp,	R,	Mer	Well Yield (L/s)	Depth or Open Interval (m)
HE77-1	15	19	52	4	W5	<0.01	72
HE77-2	12	18	52	4	W5	<0.01	72
HE77-3	8	12	52	5	W5	0.01	152
HE77-4	3	27	52	5	W5	0.04	100-152
HE77-5	9	18	52	5	W5	0.27	133-152
KE78-8	8	19	51	3	W5	<0.03	153
KE78-9	9	25	51	4	W5	0.07	102-119
KE78-10	1	23	51	4	W5	<0.01	152.7
KE78-11	8	11	51	4	W5	<0.01	306
KE78-12	5	27	50	5	W5	<0.03	91.5-128.0
HV23-1	1	4	52	4	W5	<0.01	92.0-97.4
HV24-1	4	11	51	4	W5	<0.01	86.7-89.9
48*	NE	19	51	3	W5	-	27.4
68-A*	NE	21	52	5	W5	-	43-85
72*	SW	18	51	3	W5	-	121.9

* - domestic well

7.4 MAJOR ON CHEMISTRY IN THE UPPER HORSESHOE CANYON SANDSTONE AQUIFER

Well ID	Location					Depth	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	Cl^{-}	HCO_3^{-}	ALK	NO_3^{-}	TDS	pH
	Lsd,	Sec,	Tp,	R,	Mer	(m)	←			mg/L			→	mg/L $CaCO_3$	mg/L	mg/L	
HE77-3-4	18	12	52	5	W5	104.8-105.7	30.0	1.2	364	10.3	56	94	-	658	0.2	720	8.2
HE77-4-6	13	27	52	5	W5	65.0-72.0	4.3	0.4	335	2.0	10	131	632	-	1.5	1134	8.5
HE77-5-5	9	18	52	5	W5	133.5-152.2	3.0	0.2	290	1.7	4	104	-	525	< .04	1417	8.1
HA78-2-1	11	30	52	4	W5	28.7-29.6	6.5	0.6	569	1.6	2	121	1167	-	56.0	1934	8.2
HA78-3-1	8	30	52	4	W5	23.1-24.0	9.1	0.8	694	2.2	2	104	1562	-	2.2	2388	8.2
HA78-4-1	3	29	52	4	W5	8.5-9.4	6.2	0.5	476	1.9	5	10	1174	-	2.3	1676	8.1
HA78-5-1	1	9	52	4	W5	8.5-9.4	24.3	2.5	321	2.1	124	8.6	726	-	15.2	1228	7.7
KA81-3-2	9	5	52	3	W5	46.4-47.3	4.1	0.4	364	1.3	66	33	844	-	2.3	1331	8.2
KA81-13-1	12	5	52	3	W5	42.8-43.6	6.4	1.5	314	1.6	224	7.0	477	-	9.4	1063	8.8
KA81-15-4	3	6	52	3	W5	52.5-53.4	4.6	0.3	421	1.3	4	102	850	-	1.2	1410	8.6
KE78-10-5	1	23	51	4	W5	126.6-127.4	24.0	7.9	300	9.2	47	12	793	-	5.3	1211	8.1
HV23-1	1	4	52	4	W5	92.0-97.4	4.2	1.6	255	2.3	38	30	531	-	22.0	965	8.4
HV24-2	4	11	51	4	W5	86.7-89.9	11.0	0.1	585	320.0	42	15	-	-	7.6	1561	12.5

N.L.C. - B.N.C.
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